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PRESSURE RECOVERY IN FRONT OF A DOUBLE-ROW RADIAL
AIRCRAFT ENGINE IN A TWIN-ENGINE AIRPLANE

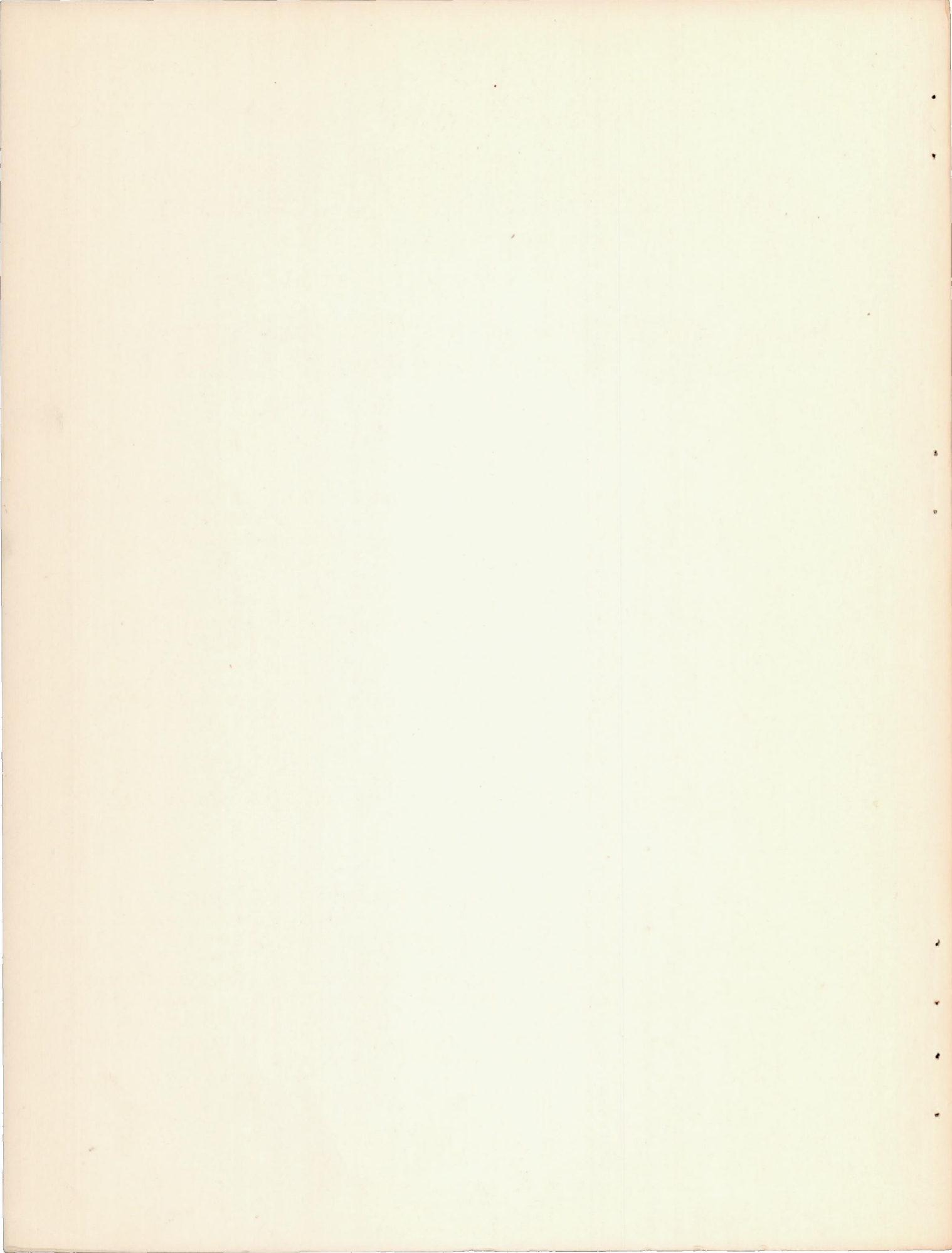
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

EFFECT IN FLIGHT OF THE PROPELLER CUFFS AND SPINNER ON PRESSURE
RECOVERY IN FRONT OF A DOUBLE-ROW RADIAL AIRCRAFT
ENGINE IN A TWIN-ENGINE AIRPLANE

By Carl Ellisman

INTRODUCTION

As part of a general program to study the cooling of reciprocating aircraft engines, an investigation was conducted with the propeller cuffs and spinner removed to determine their effect in flight on the pressure recovery of the cooling-air flow.

Preliminary data obtained from previous flight tests indicated that the inlet-pressure recovery of the cooling air was not so high as might be expected. The data from these previous flights with the cuffs and spinner installed are compared herein with the data obtained with the cuffs and spinner removed. Curves are presented to compare the pressure and temperature distribution over the front row of cylinders for flights with and without cuffs and spinner.

These tests were conducted at the request of the Army Air Forces, Materiel Command, at the Aircraft Engine Research Laboratory of the NACA at Cleveland, Ohio, during the summer and fall of 1943.

APPARATUS AND TEST PROCEDURE

The flight tests were conducted on the right engine of a twin-engine airplane powered by two 2800-cubic-inch displacement engines having a normal rating of 1500 horsepower at 2400 rpm.

The four hollow-steel blades on a $13\frac{1}{2}$ -foot propeller were fitted with shank cuffs and a large diameter spinner. Figures 1 and 2 show the propeller installation with and without cuffs and spinner. The apparatus used in the study of cuff performance was the same used for the cooling-correlation tests reported in reference 1.

The pressures measured in these tests were recorded by standard NACA pressure recorders, a recording multiple manometer of 30 cells, and a 100-tube liquid manometer photographed in flight. The pressures considered were the shielded total-head pressures in front of cylinders 2, 6, and 16 and the baffle entrance total pressures for the front bank of cylinders at the head and barrel. These pressures provide a survey of the cooling-air flow over the front of the engine.

The cooling-air temperature rise across the cylinder was measured by thermocouples such as T_{ai} , T_{ah} , and T_{ab} located on rakes in front of the engine and at the rear of each cylinder. (See figs. 3 and 4.) Thermocouples such as T_{13} and T_6 were imbedded 1/16 inch in the rear middle of the cylinder wall between the first and second circumferential fins of the head and at the rear-middle circumferential fin of the barrel, respectively. (See fig. 4.) The results of a preliminary investigation indicated that the temperatures recorded by thermocouples T_{13} and T_6 had a constant relationship to the average cylinder-head and cylinder-barrel temperatures, respectively. These thermocouple readings were therefore selected as a measure of the cylinder temperatures during flight.

In addition to the instruments for measuring pressures and temperatures and the usual engine operating conditions, a torquemeter and an inclinometer were included.

One flight without cuffs and spinner was made at a brake horsepower of approximately 1000 and an indicated airspeed of 200 miles per hour at a density altitude of 5000 feet. The engine was operated at speeds of 1800, 2100, 2400, and 2600 rpm with cowl flaps closed. One run was made with cowl flaps open at an engine speed of 2400 rpm. These runs were compared with similar runs made during the regular cooling-test program with the propeller cuffs and spinner installed. (See table I.) No ground tests were made with the cuffs and spinner removed.

RESULTS AND DISCUSSION

The comparison of test data was based on the average values of pressure recovery, cylinder temperature, and cooling-air temperature rise that were determined for the front of the engine (table I), and the temperature and pressure distribution over the front bank of cylinders (figs. 5 to 9).

The pressures p are given in terms of free-stream impact pressure q_c and were the difference between the total pressure at the measuring point and the static pressure of the free air. Pressures for individual cylinders were averaged. The baffle entrance pressure at the cylinder head was taken as the average of the pressures recorded at $H_{ah}51$, $H_{ah}52$, $H_{ah}53$, $H_{ah}54$; for cylinders 2, 6, and 16, the pressure at $H_{ai}1$ was included. The baffle entrance pressure at the cylinder barrel was taken as the average of the pressures recorded at $H_{ab}51$, $H_{ab}52$, $H_{ab}53$, including $H_{ai}2$ for cylinders 2, 6, and 16.

The cooling-air temperature rise across the head was equal to the difference between T_{ah} and T_{ai} and the cooling-air temperature rise across the barrel was equal to the difference between T_{ab} and T_{ai} . Cylinder temperatures for the head and the barrel were corrected in each case to the same cooling-air temperature observed with the cuffs and spinner off. This correction was made according to the cooling equation developed for this engine.

Because a number of thermocouples and pressure tubes were damaged or broken, only those believed to be reliable are indicated on the temperature and pressure distribution charts. (See figs. 5 to 9.)

The pressure recovery in front of the individual cylinders and the head and barrel temperatures are shown in figures 5 to 9. These figures also show the cooling-air temperature rise across the head and the barrel for comparable conditions with and without cuffs and spinner.

With the cowl flaps closed, a general increase in the pressure recovery at the bottom of the engine was obtained when the cuffs and spinner were removed. At the top of the engine, no marked difference was observed, except for a slight decrease in the recovery in front of cylinder 2. (See figs. 5 to 8.)

When the cooling-air flow was increased by opening the cowl flaps, the pressure recovery on the cylinder heads was not appreciably affected by removal of the cuffs and spinner. The cuffs and spinner were still definitely detrimental to front pressure recovery over the barrel for all cylinders except the two top cylinders 2 and 18.

The cooling-air temperature rise and cylinder-temperature patterns generally followed the pressure-recovery patterns. Cylinder 10 did not follow this trend because the cooling-air temperature rise and flow may have been affected by the proximity of the oil sump, which also served as a head baffle.

A series of motion-picture studies of the air-flow characteristics of the cowl, although limited in extent, indicated that some of the air spilled out of the top of the cowl entrance. More turbulence was evident at the top than at the bottom of the cowl. This spillage and turbulence may partly account for the low pressure recovery of the top cylinders and the comparatively higher recovery at the bottom. Figures 5 to 9 indicated that the cuffs did increase the pressure recovery for a few of the top cylinders. This increase in pressure probably was due to the fact that the cuffs helped prevent a spillage of the air from the top of the cowl.

With the cowl flaps closed and the cuffs and spinner removed, the increases in the average pressure recovery for the front cylinder heads varied from 0.01 to 0.04 q_c for the different engine speeds tested. At the barrel, the increases in pressure recovery were from 0.03 to 0.04 q_c . (See table I.)

With the cowl flaps open, no appreciable difference in the average pressure recovery was observed at the cylinder head; the increased pressure recovery at the barrel was the same as with the cowl flaps closed.

The average pressure recovery for both the head and the barrel was greater without the cuffs and spinner for most of the conditions tested. This increased pressure recovery resulted in a higher cooling-air flow, as shown by the smaller temperature rise of the cooling air across the cylinders and by the lower average cylinder temperatures.

Although the average pressure recovery at the cylinder head was lower for the flight without cuffs and spinner, the average pressure drop across the cylinder head was higher when the cowl flaps were open. The increased pressure drop across the cylinder substantiates the lower cylinder temperatures recorded as compared with those determined for the flight with cuffs and spinner.

The maximum gain in pressure recovery obtained by removing the cuffs and spinner was small. The pressure recovery over the front of the engine was never greater than 0.75 q_c .

No logical variation of the pressure recovery with engine speed was indicated by the results.

SUMMARY OF RESULTS

From limited flight tests, the effect of the cuffs and spinner on pressure recovery in front of a double-row radial engine in a twin-engine airplane indicates that:

1. The removal of the cuffs and spinner caused a slight gain in the over-all cooling-air pressure recovery obtained with the cuffs and spinner.
2. Better engine cooling in flight was obtained by removal of the cuffs and spinner.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, March 29, 1944.

REFERENCE

1. Bell, E. Barton, Morgan, James E., Disher, John H., and Hill, E. John: Flight Investigation of the Cooling Characteristics of a Two-Row Radial Engine Installation. I - Cooling Correlation. NACA TN No. 1092, 1946.

TABLE I - SPINNER AND CUFF EFFECT ON FRONT BANK OF CYLINDERS
OF A DOUBLE-ROW RADIAL AIRCRAFT ENGINE

Flight conditions									Average cooling air					Cylinder temperature		
									Pressure (p/q_c)		Temperature (°F)			temperature (°F)		
Cuffs and spinner	Indicated airspeed (mph)	Density ratio	Free-air temperature (°F)	Inclination of thrust axis	Engine speed (rpm)	Cowl flaps	Brake horsepower	Impact pressure, q_c (in. water)	Total pressure at head baffle entrance	Total pressure at barrel baffle entrance	Entrance cooling air (T_{ai})	Rise across cylinder head ($T_{ah} - T_{ai}$)	Rise across cylinder barrel ($T_{ab} - T_{ai}$)	Average head (T_{13})	Average barrel (T_6)	Figure
Off	201	0.862	56	3°04'	1828	Closed	1033	22.6	0.744	0.729	67	122	94	381	271	5
On	200	.865	60	3°46'	1806	--do--	1013	21.7	.706	.695	70	128	94	^a 388	^a 275	
Off	200	0.863	56	3°09'	2112	--do--	1000	21.9	0.730	0.717	68	126	96	382	280	6
On	200	.862	62	3°34'	2200	--do--	1017	21.8	.721	.687	74	129	101	^a 394	^a 284	
Off	201	0.861	57	3°14'	2408	--do--	1045	22.7	0.733	0.730	68	126	101	388	288	7
On	202	.863	62	3°28'	2398	--do--	1020	22.3	.712	.690	73	131	105	^a 396	^a 290	
Off	201	0.866	55	3°29'	2502	--do--	1012	22.1	0.730	0.718	69	131	104	390	295	8
On	200	.862	63	3°46'	2584	--do--	1009	20.8	.713	.687	75	134	112	^a 403	^a 301	
Off	200	0.863	56	3°42'	2408	Open	1040	21.5	0.700	0.706	67	110	79	355	260	9
On	205	.865	36	3°29'	2404	--do--	1023	22.5	.708	.662	44	116	89	^a 364	^a 273	

^aCylinder temperatures corrected to the flight conditions without the cuffs and spinner.

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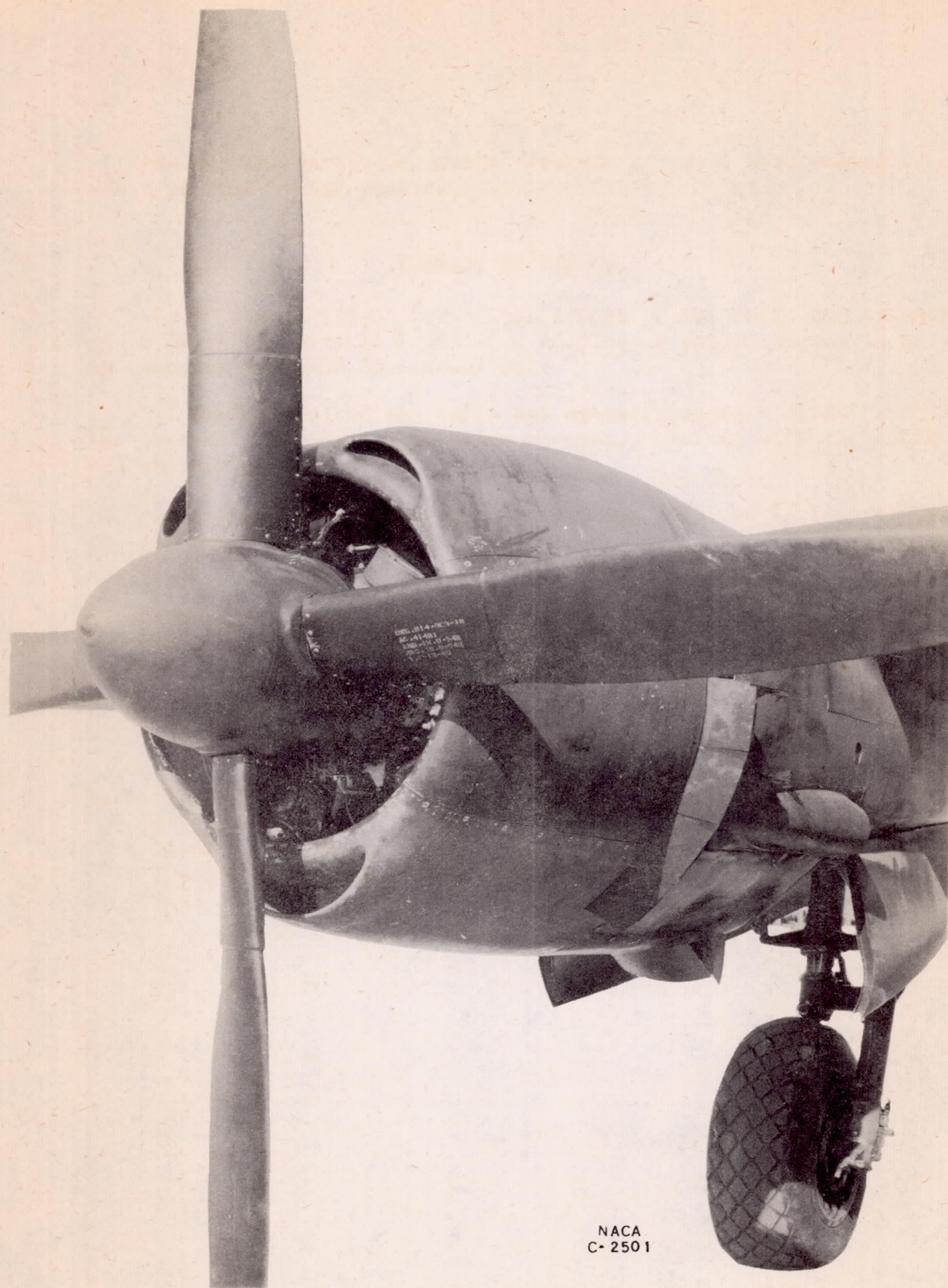


Figure 1. - Propeller equipped with shank cuffs and spinner.

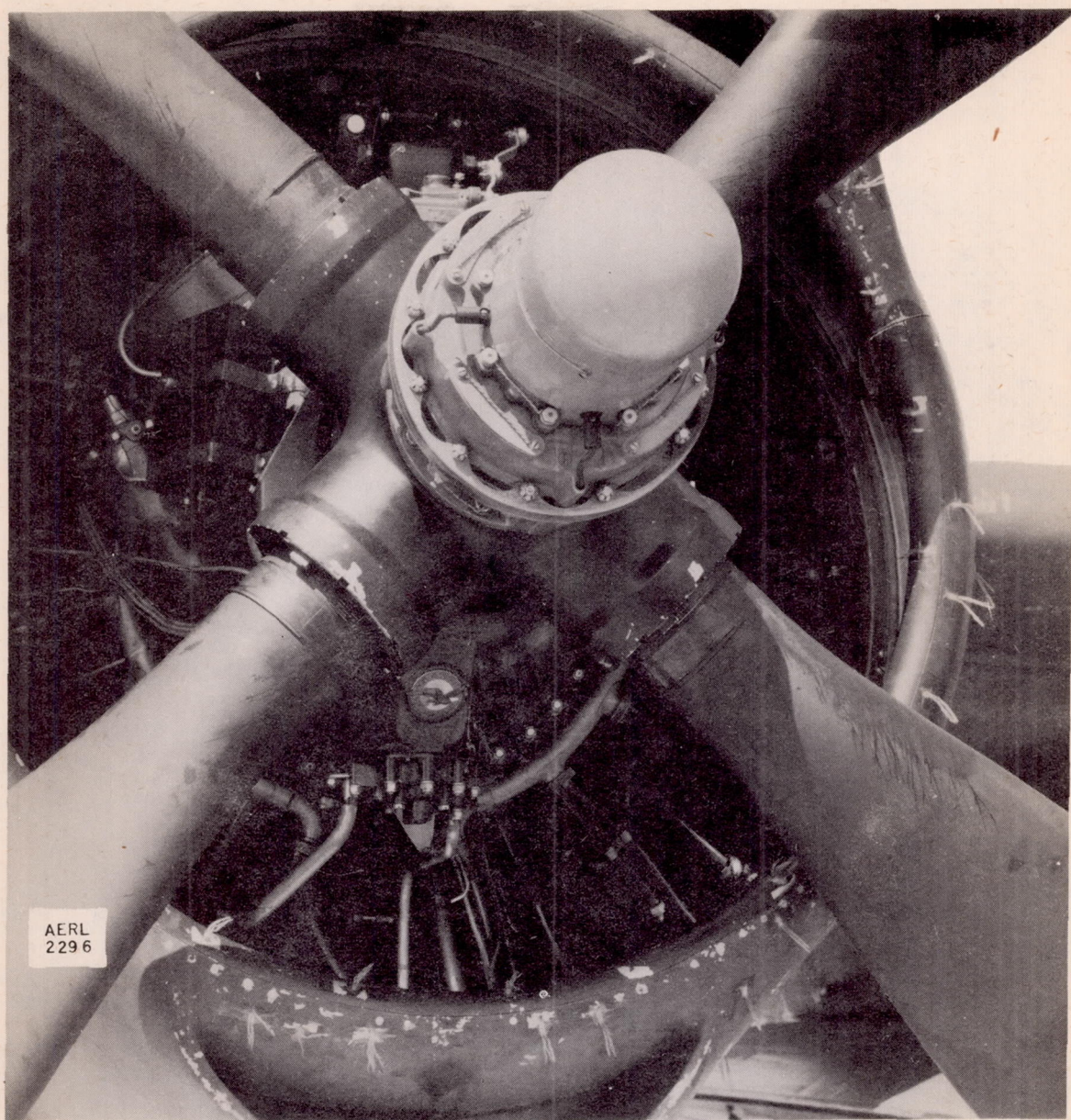


Figure 2. - Propeller mounted with shank cuffs and spinner removed.

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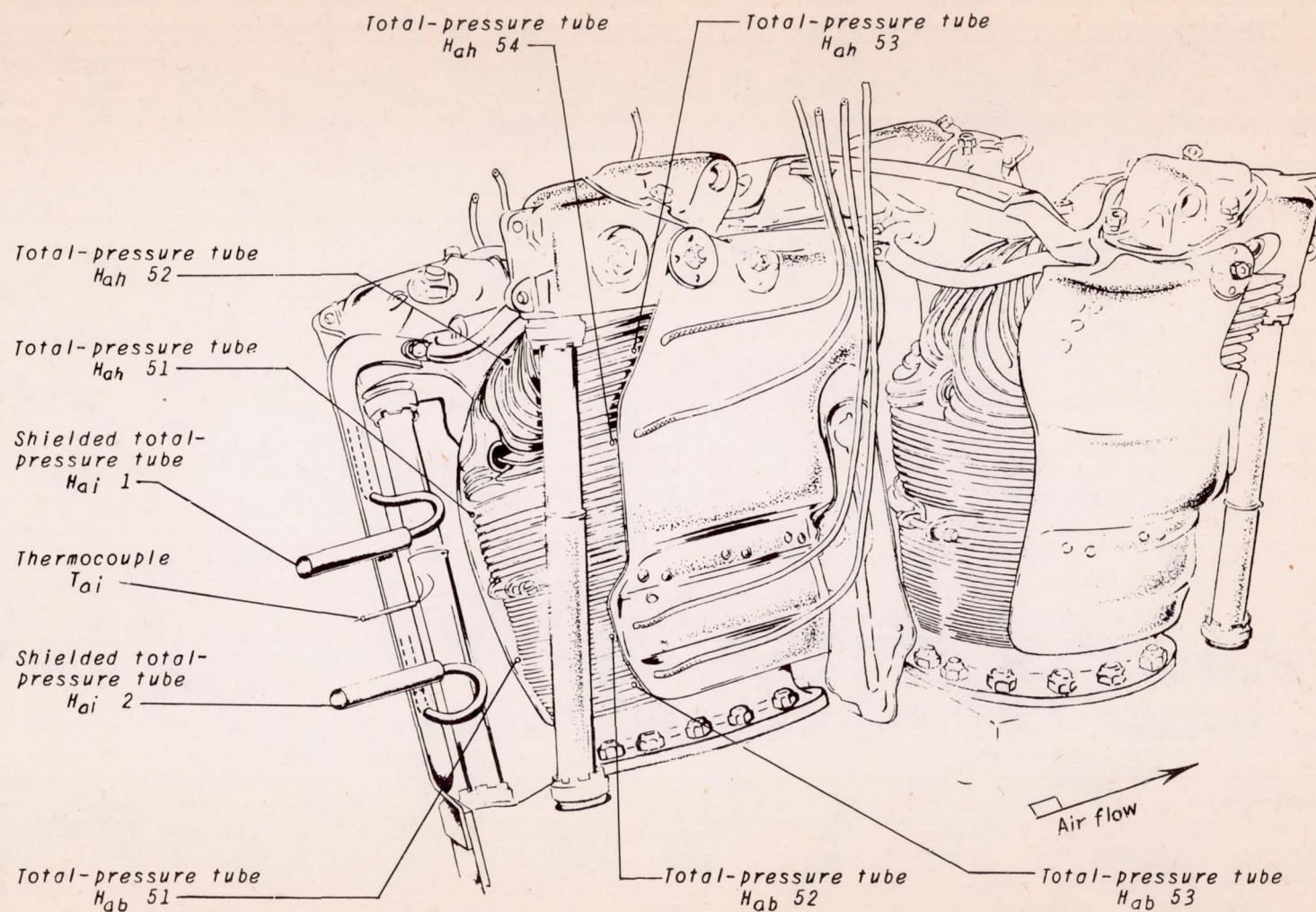


Figure 3. - Front view of front and rear cylinders showing pressure tube and thermocouple installation on front cylinder.

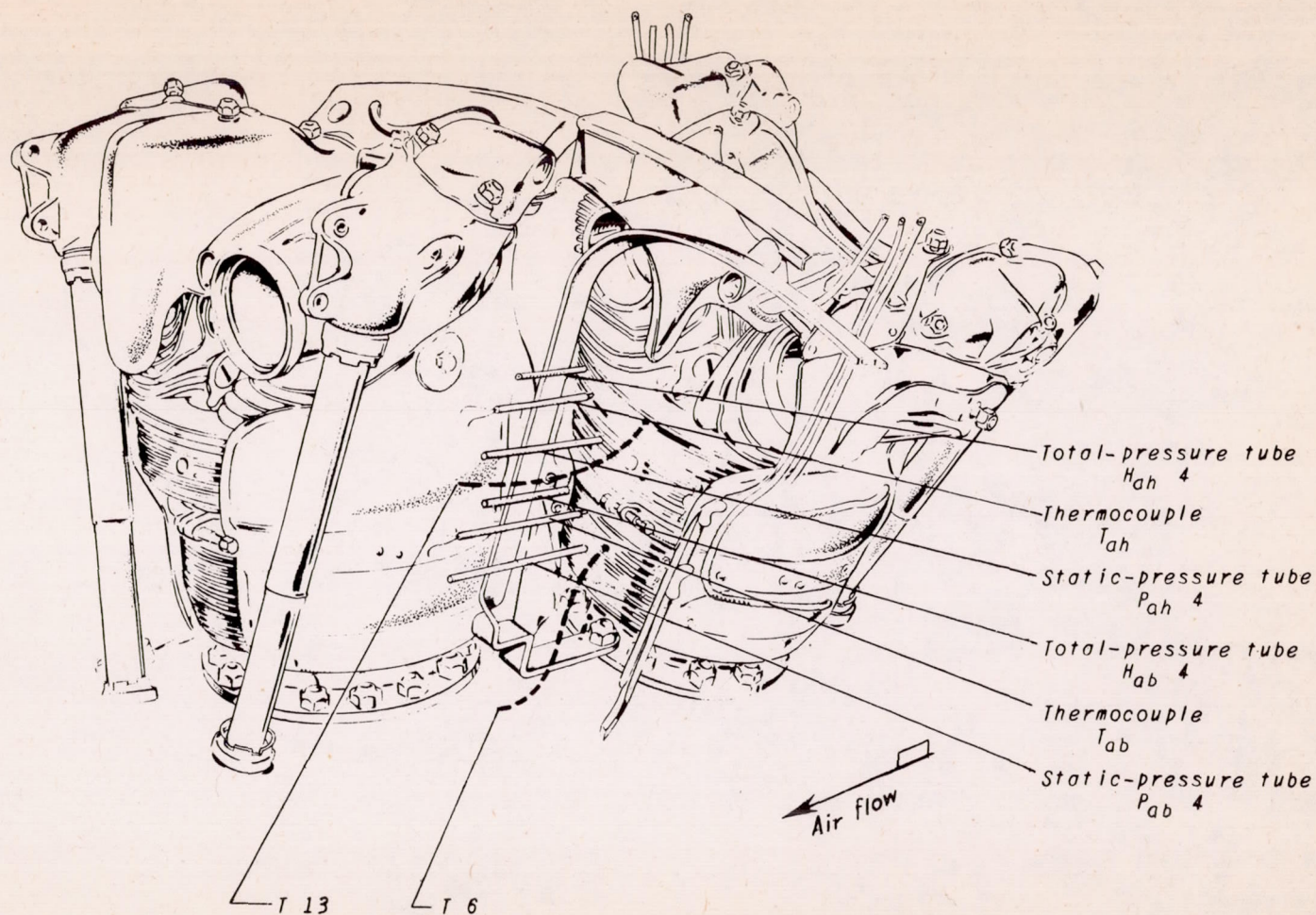


Figure 4. - Rear view of front and rear cylinders showing pressure tube and thermocouple installation on front cylinder.

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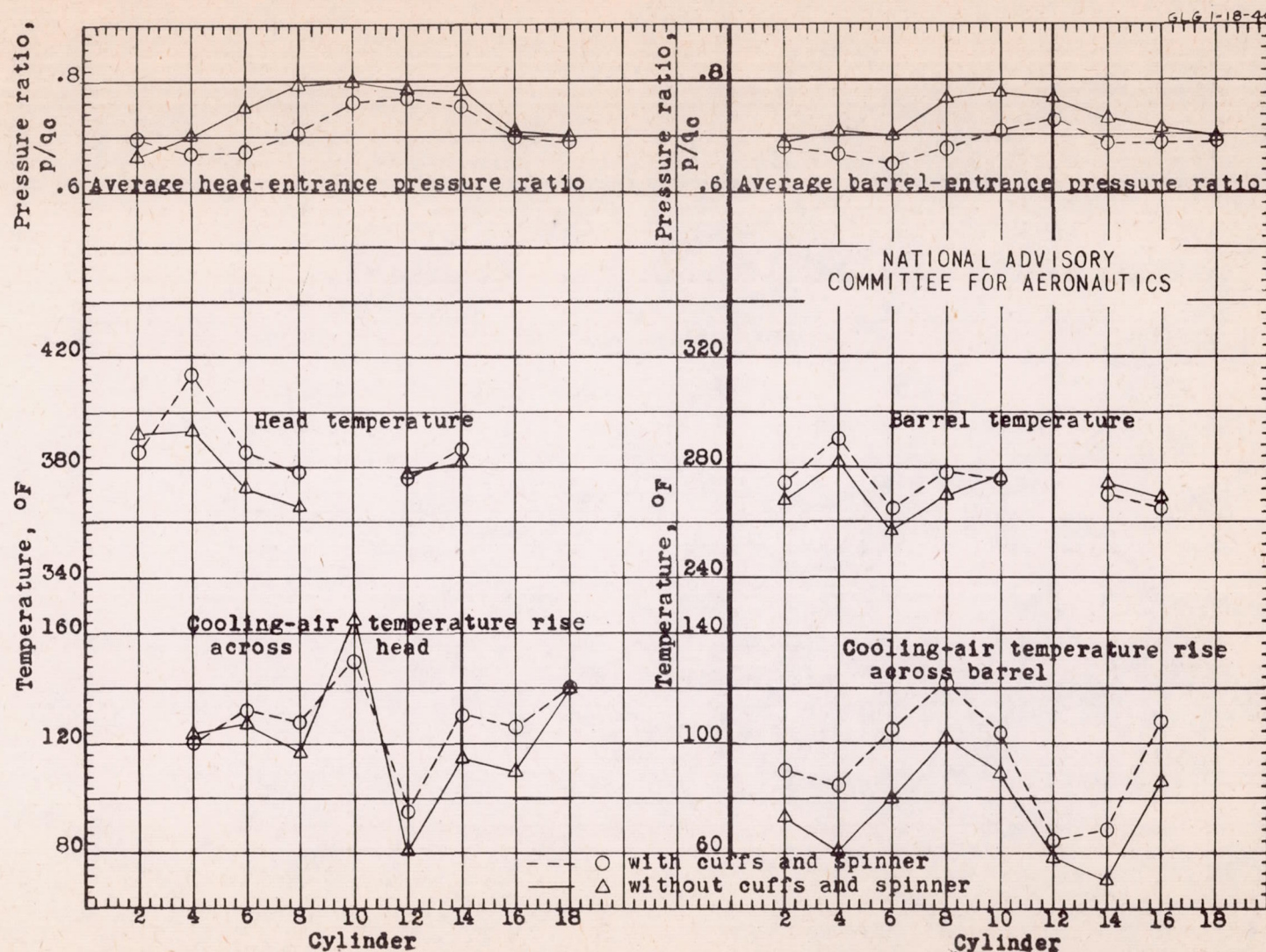


Figure 5. - Pressure and temperature distribution for front cylinders with and without propeller cuffs and spinner. Indicated airspeed, 200 miles per hour; engine speed, 1800 rpm; 1000 brake horsepower; cowl flaps closed. Cylinder temperatures with cuffs and spinner corrected to flight conditions without cuffs and spinner.

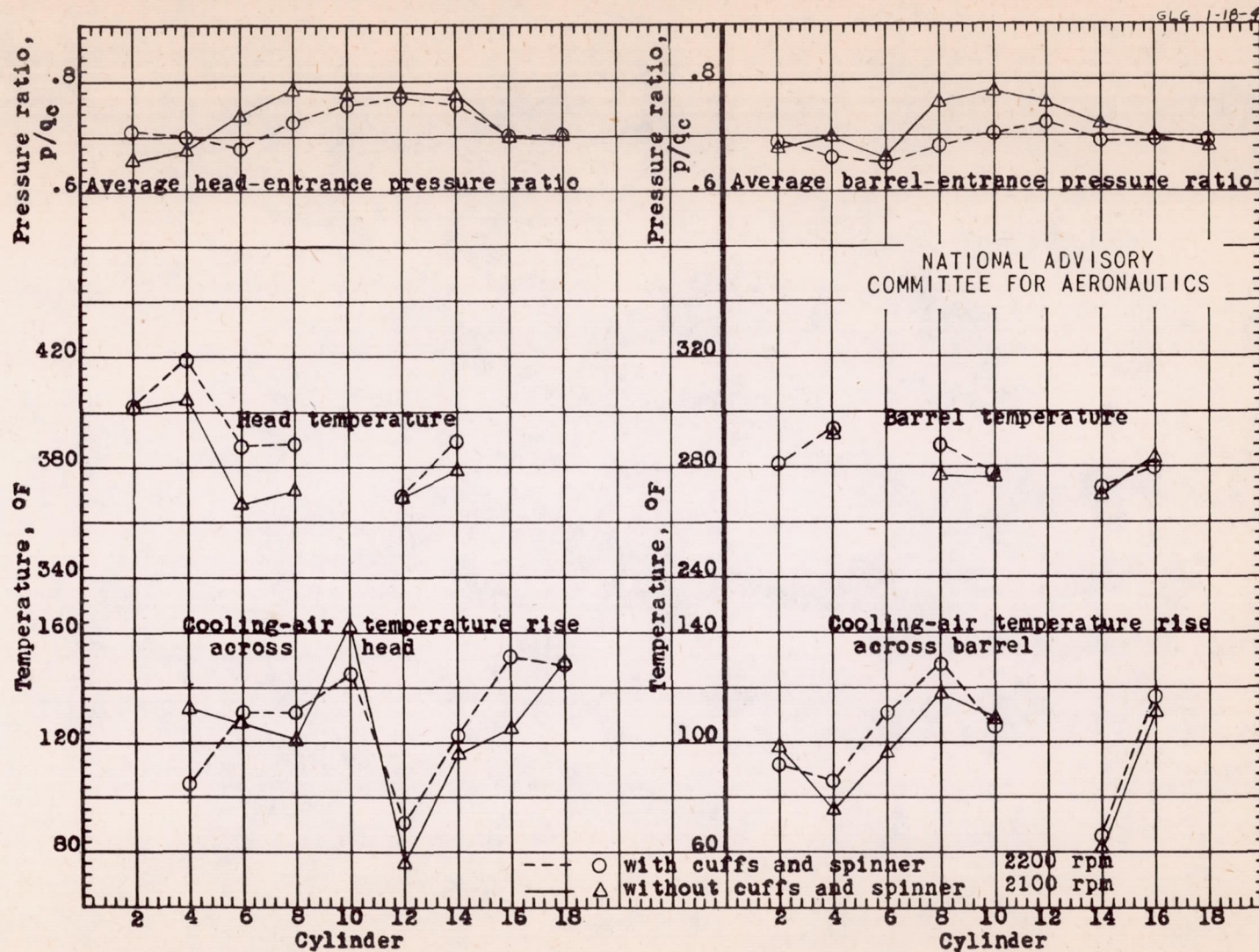


Figure 6. - Pressure and temperature distribution for front cylinders with and without propeller cuffs and spinner. Indicated airspeed, 200 miles per hour; 1000 brake horsepower; cowl flaps closed. Cylinder temperatures with cuffs and spinner corrected to flight conditions without cuffs and spinner.

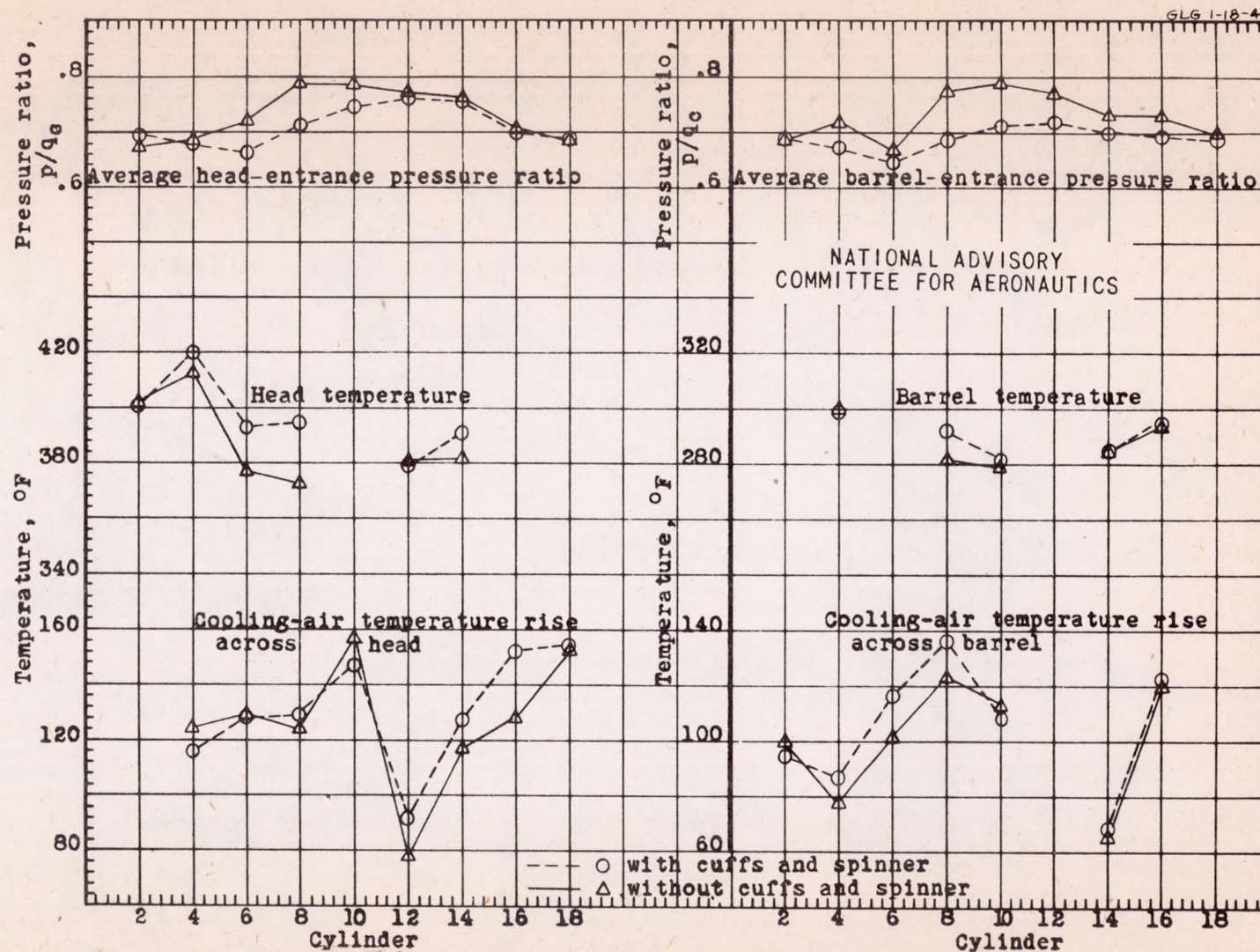


Figure 7. - Pressure and temperature distribution for front cylinders with and without propeller cuffs and spinner. Indicated airspeed, 200 miles per hour; engine speed, 2400 rpm; 1000 brake horsepower; cowl flaps closed. Cylinder temperatures with cuffs and spinner corrected to flight conditions without cuffs and spinner.

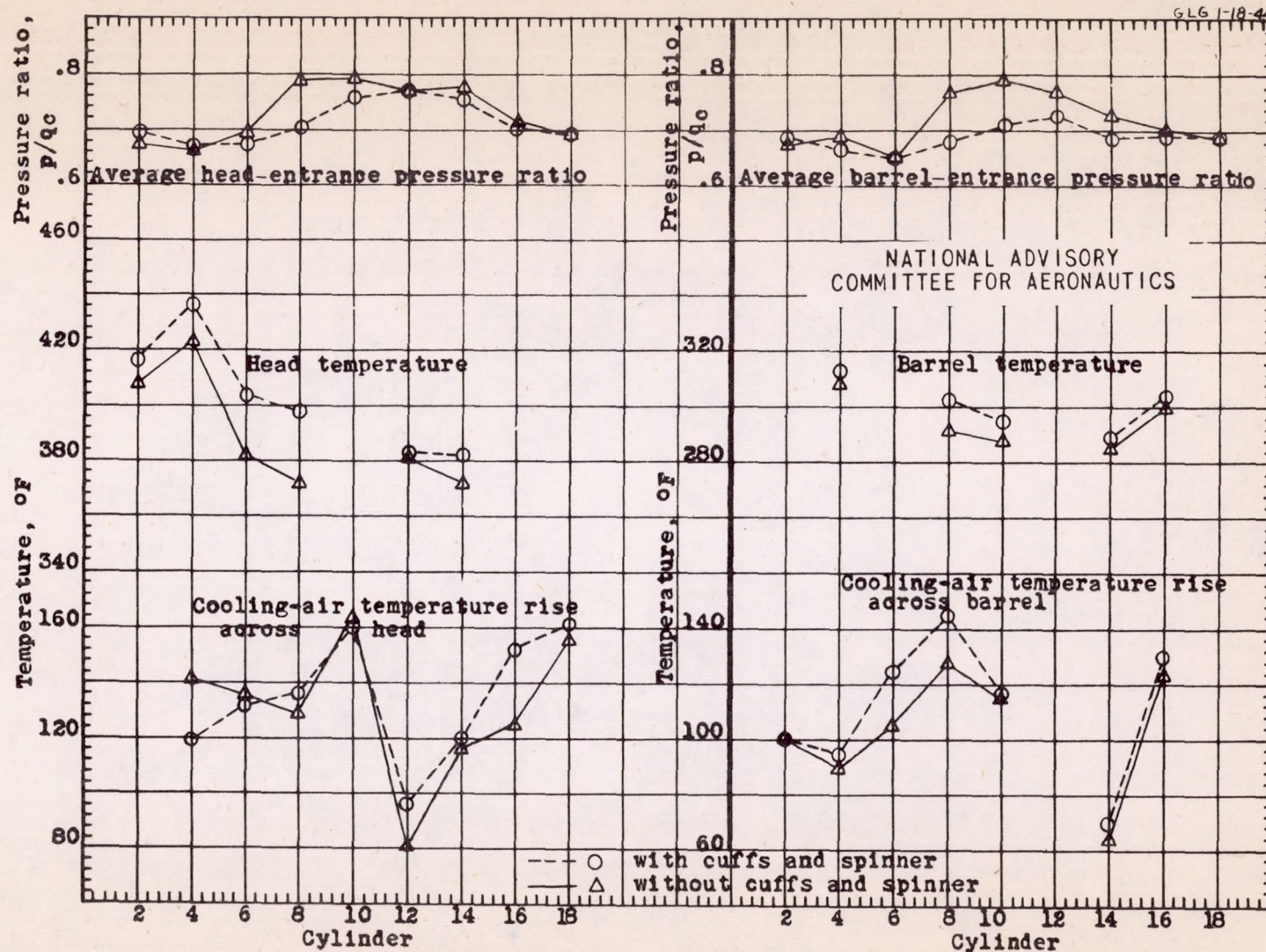


Figure 8. - Pressure and temperature distribution for front cylinders with and without propeller cuffs and spinner. Indicated airspeed, 200 miles per hour; engine speed, 2600 rpm; 1000 brake horsepower; cowl flaps closed. Cylinder temperatures with cuffs and spinner corrected to flight conditions without cuffs and spinner.

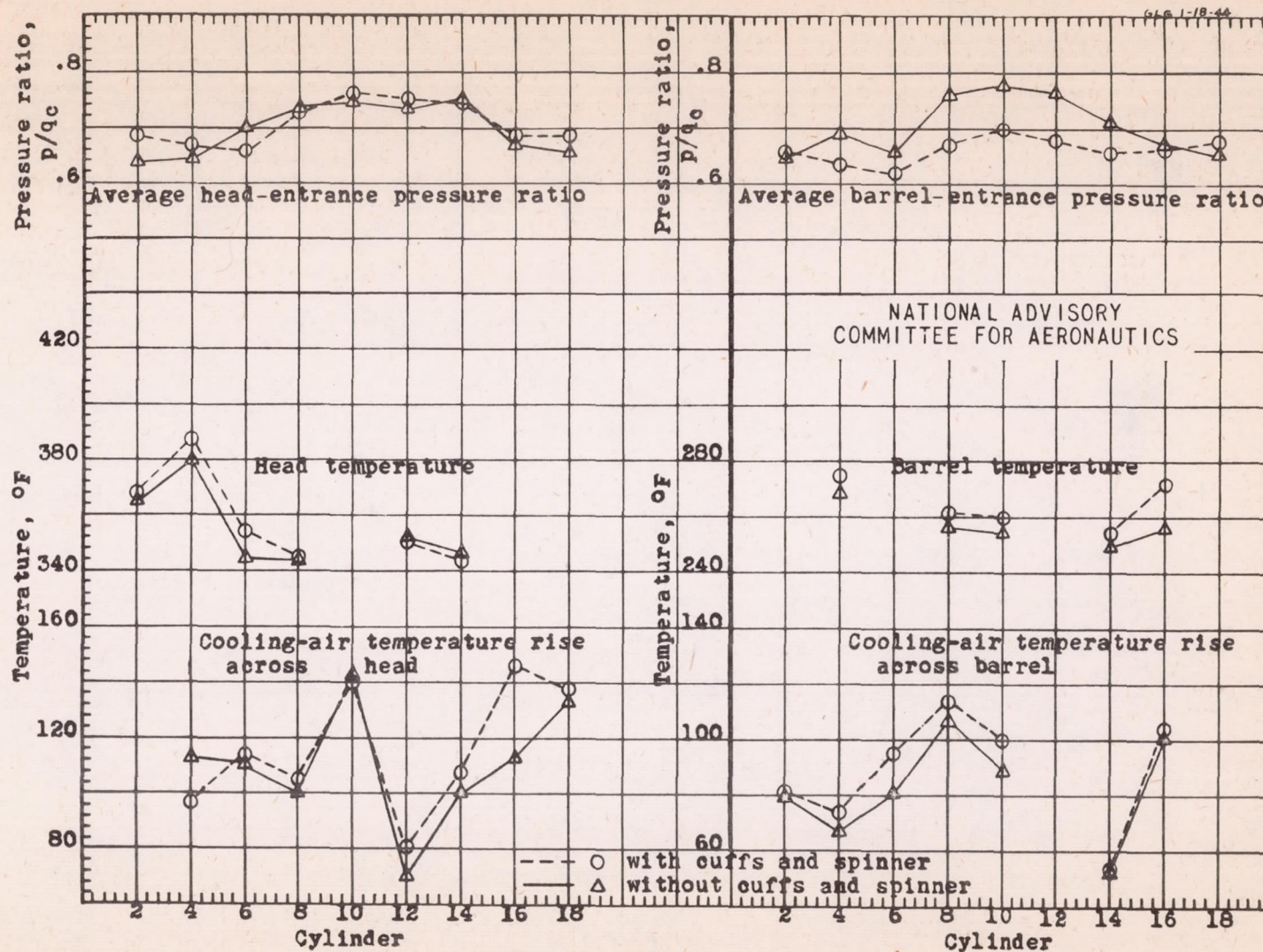


Figure 9. - Pressure and temperature distribution for front cylinders with and without propeller cuffs and spinner. Indicated airspeed, 200 miles per hour; engine speed, 2400 rpm; 1000 brake horsepower; cowl flaps open. Cylinder temperatures with cuffs and spinner corrected to flight conditions without cuffs and spinner.